8-1-1976

An investigation of solid ink density variation as determined by the acceptability of overprints in process color printing

John G. Gaston III

AN INVESTIGATION OF SOLID INK DENSITY VARIATION AS DETERMINED BY THE ACCEPTABILITY OF OVERPRINTS IN PROCESS COLOR PRINTING

BY

JOHN G. GASTON, III

An Abstract

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Printing in the College of Graphic Arts and Photography of the Rochester Institute of Technology

August 1976

Thesis Advisor: Professor Miles Southworth

School of Printing
Rochester Institute of Technology
Rochester, New York

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's Thesis of

John Garretson Gaston, III

with a major in PRINTING TECHNOLOGY has been approved by the Thesis Committee as satisfactory for the thesis requirement for the Master of Science degree at the convocation of

MAY 1981
date

Thesis Committee: Miles Southworth
Thesis Adviser

Name Illegible
Graduate Advisor

Mark J. Guldiu
Director or Designate

ABSTRACT

In order to establish limits which are representative of the allowable variation in solid ink density (SID) of the single process colors, as determined by the allowable variability of their overprints, a study was conducted utilizing fourteen (14) experienced color observers selected from printing companies in the Greater Rochester area.

Printed color patches, at the 70% tint level of cyan, magenta, yellow, red (M+Y), green (Y+C), blue (M+C) and three-color overprints (Y+M+C), were shown to observers, individually. In each group, the observer was asked to accept or reject the patch when compared to the reference standard in that group. The solid ink density of the process color or colors, which created the patch, were measured to determine the allowable variation in SID for the single colors, two and three-color overprints.

The findings indicate that there is greater allowable variation when comparing single colors alone than when comparing their overprints. The standard deviations (S), ranges (R) and ($\bar{R}$)average ranges of the allowable variation in SID for the colors utilized were:

	S	R	$\overline{R}$
Yellow	0.077	0.29	0.18
Magenta	0.081	0.30	0.21
Cyan	0.077	0.42	0.19

These findings and others would indicate that present standards, usually assigned to good quality color printing, such as ± 0.05, are unrealistic and unnecessary. The ranges allowed by these experienced color observers were as much as 0.42.

Other significant findings show that magenta-reds are preferred to yellow-reds and that overall, increases in the magenta solid ink density were allowed more than increases in the cyan SID. There is conclusive evidence to show that these observers accepted greater variation in lightness than in hue and therefore would not accept as much hue change as lightness change.

There is further evidence to indicate that it is important to monitor the hue change in the three-color overprints and near neutral colors, since these observers failed to accept comparatively small changes in SID in this region. It is, therefore, appropriate that the pressman vary SID on the press to maintain consistency in the overprints.

In conclusion, it may be stated that densitometric values have been established which represent the

allowable variation in SID of the single colors. These values are representative of the levels of the process colors on the press and could be applied towards a more effective method of controlling process color printing at the press.

Abstract Approved:

Miles Southworth
Thesis Advisor
Professor, School or Printing
Rochester Institute of Technology

2/11/81
Date

AN INVESTIGATION OF SOLID INK DENSITY VARIATION AS DETERMINED BY THE ACCEPTABILITY OF OVERPRINTS IN PROCESS COLOR PRINTING

BY

JOHN G. GASTON, III

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Printing in the College of Graphic Arts and Photography of the Rochester Institute of Technology

August, 1976

Thesis Advisor: Professor Miles Southworth

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to the following printing companies in the Greater Rochester area which were most cooperative and instrumental in the collection of data, enabling me to carry out this thesis:

The Case-Hoyt Corporation, Great Lakes Press Corporation, The Rochester Polychrome Press, Inc., and the G. M. Du Bois Corporation.

And finally, I wish to thank my thesis advisor, Professor Miles Southworth, who provided much of the inspiration and impetus to carry out and complete this thesis.

I. INTRODUCTION

In order to develop an efficient and accurate system for controlling and monitoring the allowable variation in solid ink density at the press, it is necessary to take into account some of the variables associated with the graphic reproduction process as well as perceptual variables which can be a source of disagreement in assessing the quality of process color printing. Through a better understanding of human perceptual variables, information for better control of process color printing at the press might be obtained. Any by reducing the human error in the evaluation of process color printing at the press, the chances for error in the control of the printing will be minimized. During an average run, where two or more colors are applied to a substrate, the variation in solid ink density may be considerable for each of the process colors depending on the job requirements and the individual operator of the press. The additive effect of this variation is exhibited in changes in hue of the overprint colors. The question arises: What variation in solid ink density of the single colors may be tollerated before the observer will fail to accept the overprint color?

If it is true that all jobs, which are accepted by the customer, have some degree of variation in the solid ink density of the single colors, then information concerning the allowable variation in solid ink density (SID), as determined by the color observer, might be of practical use in monitoring the process.

In the halftone process, tint density is dependent on the solid ink film and the area which it covers. The combined effect of the solid ink film and the substrate will effect the characteristics of the light reaching the observer. The ink film acts as a filter absorbing and transmitting light according to the spectral selectivity of the pigments utilized and their composition. It is, therefore, important to be able to monitor the solid ink film during the press run.

Since cyan (C), magenta (M), yellow (Y), their two-color overprints; red (M+Y), green (Y+C), blue (M+C) and the three-color overprints (C+M+Y) and the substrate on which they are printed, give rise to the perception of the gamut of colors, it is necessary to monitor their individual amounts at the press. Given that the dot area remains essentially constant, a change in the solid ink density may create a visual change in the overprint. The acceptability of the overprints, therefore, may be affected by variations in the solid ink density of the single colors. By measuring the variation in solid ink density of the single colors for a given range of overprints, a relationship may be established between the allowable variation in the single colors and the acceptability of their overprints.

II. LITERATURE SEARCH

A search of the literature indicates that there is little information currently available with respect to the allowable variation in solid ink density (SID) of the single colors as determined by the acceptability of their overprints. However, there is evidence that a study of solid ink density variation as determined by the acceptability of overprints might be of value to the process color printer.

In Book Production Industry Magazine, September 1975, Paul R. Guy states that some of the important factors relevant to controlling color on the press are: "color strength of the individual inks utilized, hue of the overprint colors and gray balance."[1] He also states that "the hue of red resulting from overprinting yellow and magenta solids can be adjusted by changing the printed strengths of the two inks involved; a warm red indicates the yellow is relatively stronger, a cooler red is the result of relatively stronger magenta." Most importantly, Guy states that "several industry-wide color surveys by G.A.T.F. and others have shown that the hues of all secondary colors (Red=Y+M, Green=Y+C, Blue=M+C) are poorly controlled on the press."[2] It is inferred that the control of the overprint colors is dependent on the relative densities of the single colors.

"In comparing two colours, both of which have been made from the same basic pigments, the densitometric differences represent colour differences, which by manipulation of pigment concentration and ink film thickness can be made smaller until the densitometric difference is zero and the two colours being compared are identical."[3] More importantly, "during a run, the densitometer can give accurate information on how the printed colour compares with the pass sheet or some other standard."[4] In order to establish a system for controlling solid ink density on the press sheet, it is important that "in addition to the solid patches of the four inks printed alone, the color bar should include overprints of the three colors in pairs. The hue of the two-color overprints can be evaluated and used as a control at the startup and throughout the run." The hue of overprints is influenced by the relative running strengths and by the trapping of the two inks involved.[5]

Controversy concerning the justification for using the densitometer as a device for controlling process color printing variables is well founded. However, it is inevitable that there will be limitations associated with any color specification or measurement system. The problem lies in the assigning of numerical values to perceptable color changes on the press sheet.

"Current methods of approving process color work requires complete understanding between the person actually doing the color matching and the ultimate customer who must approve the color match."[6] This is sometimes difficult, because the people in between may have little knowledge of the basic requirements for arriving at the desired standard.

Lack of agreement between individuals approving the job may also cause disagreement with respect to job acceptability, or the difficulty may also have multiple sources, such as two consecutive shifts in the same plant printing the same job. The individual responsible for controlling the press on the first shift may have entirely different tollerances for variations in color on the press sheet than the individual controlling the press on the second shift.

Properly applied, the densitometer may provide accurate and consistent data representative of process variability normally associated with process color printing during a press run. This would afford an expedient and reliable method for communicating data between individuals responsible for the running and completion of a particular job.

CHAPTER II. FOOTNOTES

[1]Guy, Paul R. "Process Color Reproduction," Book Production Industry Magazine, September 1975, pp. 39-44

[2]Guy (1975)

[3]Kollmorgen Corporation of America "The Densitometer In The Graphic Arts," Printing World Magazine, January 24, 1973 p. 74

[4]Kollmorgen Corporation (1973)

[5]Guy (1975)

[6]Richardson, G. W. "Color Matching," Gravure Technical Association Bulletin, Winter 1974, pp. 78-80

III. INTRODUCTION TO HYPOTHESIS

In order to define and measure the allowable variation in the single colors as determined by the experienced color observer in process printing, it is necessary to investigate the mechanism through which the observer differentiates changes in color.

Color as perceived by the observer in process printing is determined by a psychophysical reaction between the eye and the brain. More specifically, the eye transmits information to the brain in the form of neural activity or electrical impulses which are translated by the brain as visual sensations. Individual tollerances to changes in color on the press sheet may vary depending on the viewing conditions and personal judgement of the observer and other factors which I will discuss. These elements may be manifest in the perception of color in the comparison of press sheets during a run.

Conditions which influence the observer's perception of colors on a press sheet are: the color quality of the light under which the sample is viewed, the proximity of other colors, and the surfact texture of the substrate on which the image is printed. Two of these variables can be controlled by utilizing a standardized light source and paper stock with uniform reflectance. The proximity of other colors, however, is one element over which the printer seldom has control.

Assuming that it is possible to produce a balanced set of separations, there are numerous variables which contribute to changes in the printed image. However, when the press is running all previous variables will be manifest in the printed image on the press sheet. Previous labor and materials which went into the job in the pre-press operations, cannot be recovered. The acceptability of the job at this point depends on variability at the press. If the printed product is to be acceptable to the customer, it is important that the proper decisions be made by the printer at the press during the run.

The human element becomes most critical at the press with respect to job acceptability. Tollerances to changes in the single colors and overprints on the press sheet may be different for different individuals. Since the experienced color printer is most familiar with process variations as they relate to color printing at the press, it is particularly important to establish tollerances for color variations as determined by the experienced color observer.

The question still remains: What are the limits of the solid ink density? The answer to this question is one of great complexity which I hope to deal with in this thesis. If limits of acceptability with respect to the overprint colors may be established, these may then be related to changes in solid ink density of the single colors, which were utilized to produce the overprints.

It is important to monitor changes in the overprints, because the evaluator is more concerned about changes in hue than density. Therefore, comparatively smaller changes in SID will be detected in the overprints.

In order to accurately control color reproduction at the press during a run, it is advisable to use the assistance of a reflection densitometer which is capable of assigning numerical values without the intervention of human color vision. Although the human eye is very sensitive to small changes in hue and saturation for given chromaticities, there may be a considerable amount of variability with respect to the repeatability in matching samples to a reference standard. The utilization of a reflection densitometer at the press should help reduce error and assist in control of the process.

"The response of the eye and brain to differences in the amount of light transmitted or reflected follows a somewhat logarithmic pattern."[1] Acceptability limits of the overprints could, therefore, be related to variations in SID of the single colors which comprise that overprint. It would follow that the allowable variation in solid ink density of process colors alone may be determined by studying the visual changes in the overprint colors as determined by the experienced color observer.

If there is a reasonable amount of control over physical printing variables at the press, i.e., the density of solid ink film at the time of transfer from blanket to substrate, trapping, dot gain, and slur, then the densitometer would afford an accurate and expedient means for monitoring changes in color density during the process. However, one recurrent and sometimes uncontrollable problem is the human element which determines the limits of acceptability of the overprint colors and therefore the acceptance of the entire press sheet.

In order to utilize the densitometer effectively for controlling process color printing at the press, acceptability limits of the overprint colors must be expressed in terms of variations in solid ink density of the single colors. It is, therefore, important to establish limits which are representative of the allowable variation in solid ink density by observing the overprints.

CHAPTER III. FOOTNOTES

[1]Yawn, Howard "Reflection Densitometry In Controlling Proofing," Photoplatemaker's Bulletin, Vol. 63, No. 12, May 1974

HYPOTHESIS

Densitometric values can be established for the allowable variation in solid ink density of the single colors as determined by the acceptability of their overprints.

OBJECTIVES

In order to define and limit the research and experimentation procedures with respect to the above hypothesis, the objectives of this thesis are as follows:

1. To determine the allowable variation in solid ink density of the single colors based on the acceptability of their overprints.
2. To utilize "experienced color observers" as my population for obtaining statistical data.
3. To design an experiment which may be related to "average" process color printing conditions.
4. To express the limits of the allowable variation in terms of density values which could then be better understood and applied during future press runs.

IV. EXPERIMENTAL PROCEDURE

Color Metrics

The analysis and measurement of color may be broadly classified as color metrics. The purpose of color metrics is to express color differences as numerical values utilizing standard methodology. One such system of defining visual color changes is just noticeable differences (JND's). "As applied to color work, a real or imagined difference in stimuli becomes a standard and differences in pairs of the other stimuli are modified until each of these differences appear equal to that of the standard."[1]

Analagous to the concept of JND's is color difference specification by paired comparisons from a given standard. In this type of experiment, the observer determines what he considers to be an allowable variation from the standard. Although the paired comparison method may be subject to considerable variation among observers, it is a more effective method of specifying tollerances for a given range of colors than JND's.

For whatever color specification system is chosen, it may be extremely difficult to assign numerical values to specific sense differences. It is, however, feasible to determine observer acceptance limits based on repeated comparisons of samples to a reference standard. Values may then be assigned to the limits of acceptance based on measured differences between the reference standard and "acceptable" samples.

In developing such a color metric, it is necessary to design an experimental situation which is representative of the situation in which the metric will be applied. This metric will be defined and limited by the experimental conditions and techniques utilized. Conclusions which are drawn from this type of experimental work may be limited and must not be overestimated or generalized. It is appropriate that the perceptual variables related to the observer in process color printing be pointed out before designing an experiment.

The Observer

"There is an amazing discrepancy in the ability of any person to discriminate between two juxtaposed colors and his ability to pick a color from an array that will match one he has just seen separately."[2] It is, therefore, appropriate to utilize a paired comparison system for determining color tollerances of an individual.

With respect to the press sheet, it is common practice to compare specific areas or patches of colors on an approved sheet to the same area or patch on a sample sheet during the run. This technique is essentially a paired comparison. It is, therefore, appropriate to design a color metric which will measure the allowable variation in solid ink density at the press using a paired comparison technique as judged by experienced color observers.

An area on the approved press sheet should represent the standard and all successive samples will be taken from press sheets during the run comparing identical areas to the standard. An observer may accept or reject the patch according to its deviation from the standard. This technique is utilized for obtaining data in this experiment which will be discussed in the next chapter.

CHAPTER IV. FOOTNOTES

[1]Evans/Hanson/Brewer The Principles of Photography Eastman Kodak Company, (New York), John Wiley & Sons, Inc., 1953

[2]Evans, Ralph M. The Perception of Color, (New York) John Wiely & Sons, Inc. 1974

V. EXPERIMENTAL DESIGN

In order to print a range of single colors, two and three-color overprints, which could be utilized to determine the allowable variation in SID of the single colors as determined by the acceptability of their overprints, diagrams representing the actual positions of the single colors with tint values of 30%, 50%, 70% and solid ink density (SID) were prepared. The single colors were positioned so that they would overprint in an area approximately one (1) inch square. The single colors utilized are the process colors yellow (Y), magenta (M), and cyan (C). The two-color overprints formed by the single colors combined are red (Y+M), green (Y+C), and blue (M+C). The three color overprints and neutral colors are formed by all three single colors (Y+M+C). Figure 1 shows the configuration of the tints. It should be noted that only the 70% tint level is utilized in the tests.

Using rubylith, the printing areas were masked out according to Figure 1. In this manner, three separate film positives were prepared, one for each single color yellow (Y), magenta (M), and cyan (C). The three sheets were then registered using a Kodak Registration Punch.

Three film negatives were then produced by exposing each rubylith positive in contact with lith film. Each film negative was, in turn, register punched prior to exposure to ensure proper registration of all colors.

CONFIGURATION OF PRINTED SAMPLE COLOR
PATCHES-THREE COLOR OVERPRINT

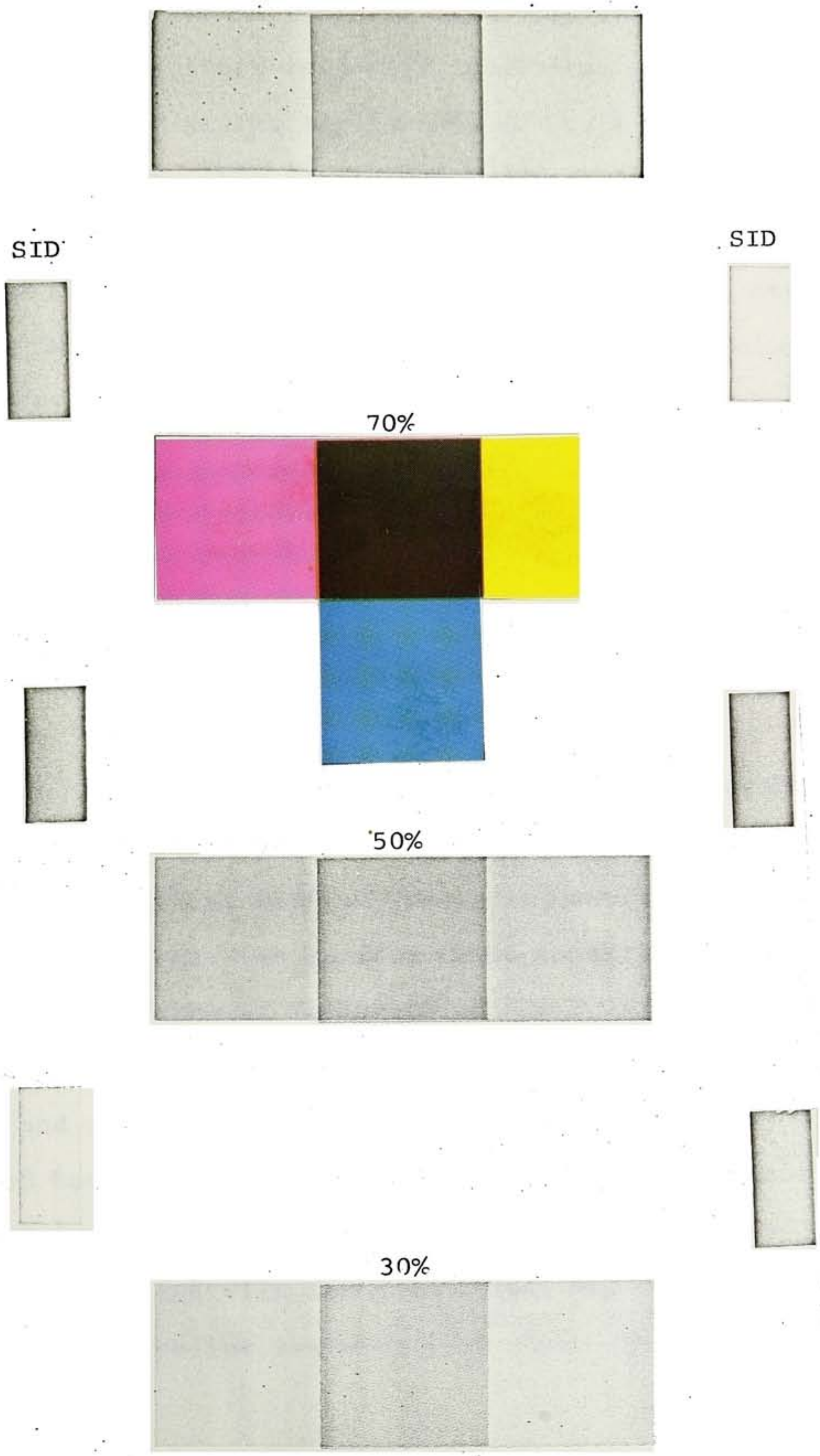

Figure 1

Prepared screen tints of 30%, 50%, 70%, and no tints, were placed in their respective positions of the film negatives. Proper screen angles were determined with a screen angle template. The screen ruling for all tints was 100 lines/inch.

A color proof of the three color overprints was made using 3M Color Key Proofing System. The proof indicated that all screen angles were in proper position and that the same tint value was printing in all three colors. Equal tint values could be determined by the visual check of the proof, which appeared neutral in the three-color overprint.

Printing Color Patches

In selecting the most appropriate weight and surface characteristics of paper on which to print, the ultimate viewing conditions were an important consideration. Taking into account that the surface characteristics of the paper chosen would have an influence on the observer, and that "high gloss is perceived in the illumination frame of reference and so should be completely excluded if possible,"[1] a coated book paper was selected.

Using a reflection densitometer to monitor the density of the solid ink film for each color, the possible density range of the yellow ink with that plate, press, paper, etc., combination was determined. Beginning at the highest solid ink density, approximately thirty (30) sheets were printed at every .10 decrement in solid ink density (SID) until a minimum solid ink density was reached. The minimum SID was determined to be the point at which there was a significant loss of dot sharpness. In this manner a "range" of single colors, varying in solid ink density, was printed.

Being certain that all traces of the yellow ink were removed from the press, the same procedure was utilized to print the magenta single color patches. To provide a range of yellow and magenta overprints, magenta was overprinted at each density level of yellow previously printed.

Allowing sufficient time for the yellow and magenta overprints to dry and again removing all traces of ink from the press, the cyan single color was printed using the same procedure as previously mentioned. In order to create a range of yellow and cyan overprints, each level of yellow, previously printed, was overprinted with each level of cyan. Using the same procedure, all previously printed levels of magenta were overprinted with every level of cyan, thereby creating the magenta and cyan overprints.

In order to produce a range of three-color overprints, a range of yellow and magenta overprints, in which one solid ink density was increasing while the other was decreasing, was selected. This was determined by measuring the yellow solid ink density with a blue filter and the magenta solid ink density with a green filter on the reflection densitometer. Using these levels of magenta and yellow overprints, the cyan was printed. And by varying the SID of cyan on the red (M+Y) overprints a range of three-color overprints was produced.

It should be pointed out that although the solid ink density was monitored for each single color to obtain the desired increments in solid ink density, there was still considerable variation at each level. Since all tints were positioned in line on the plate, there was little, if any, variation across the sheet. However, variation at each density level printed caused a considerable variation in the overprint colors. This was advantageous in producing a usable range of single colors and their overprints with the necessary deviations in solid ink density.

Data

1. Plates-3M Type Kplus 11"x18½"x.005PB
   batch no. GC1315, April, 1977

2. Processing:

   Exposed 2 min.-NuArc Exposure Unit
   Dev.-3M Subtractive Plate Dev. 30 sec.
   Gum - " " Gum 1 min.

3. Press - AB Dick 360 CD Duplicator
   Sheet Fed

4. Inks - AB Dick:
   Yellow 3-5530 C
   Magenta 3-5425 C
   Cyan 3-5120 C

5. Printing Order for all samples:

   #1 Yellow
   #2 Magenta
   #3 Cyan

Density Measurement of Patches

In order to standardize experimental procedures and eliminate possible sources of variability in the density measurements, a GAM Model 126P Densitometer was used to determine the SID of each color patch utilized in the experiment. The densitometer was zeroed to the paper base on which the sample color patches were printed.

The solid ink densities for each of the single colors were obtained using the Wratten No. 25 red, No. 58 green, and No. 47 blue filters for cyan, magenta, and yellow solid ink densities. To ensure accuracy in the data, an average of three readings was taken for each individual sample patch with each filter. The densitometer was periodically checked for consistency and calibration.

The Experienced Color Observer

The definition of the "experienced color observer", as applied to this test population is: that individual who on a day-to-day basis is responsible for determining the allowable variation in color on the press sheet during a run.

It should be emphasized that the experienced color observer may be any individual who is responsible for assessing the quality of color printing. The experienced color observer may also be responsible for making a change in the process during the press run.

In order to obtain a representative population for the experimental analysis, the observers were selected from four color printing companies in the Greater Rochester, New York area and from the Rochester Institute of Technology. The total test population included fifteen (15) experienced color observers, eleven (11) from industry and four (4) from the Rochester Institute of Technology Faculty and Staff. All individuals were representative of an experienced color observer as previously defined.

Each company was informed of the nature of the experiment to be carried out and the information desired. Appointments were arranged with the selected observer so that interruptions during the testing period would be minimized.

Paired Comparison Test

Before testing each individual observer, the color temperature of the light source in the viewing area was checked and verified to be $5000^{o}K$, $\pm 25^{o}$. All distracting objects and possible sources of interference were removed from the viewing area. Each observer was then tested for defective color vision utilizing the American Optical Company H-R-R Pseudoisochromatic Plates. If zero (0) color deficiencies were determined, then testing commenced.

The following instructions were then read to each observer being tested: Start: "The color patches which I will show to you are representative of colors on a press sheet from an 'average' press run. There are seven groups of colors in all, (C, M, Y, R, G, B and Neutrals). For each group, there is a standard which represents a color on an approved press sheet from that run. Each patch will be compared to the standard in succession. You will accept the patch if you consider it to be within the control limits of an average press run and you will reject the patch if you consider it to be outside the control limits of an average press run. If you are undecided about a particular patch, consider it acceptable."

After placing the reference standard in front of the observer on a viewing platform at approximately a 45 degree angle, the tests commenced. The platform was designed to hold two samples at a 45 degree angle thereby minimizing specular reflections from the surface of the patches and providing uniform positioning of all samples.

In order to standardize the testing procedure for all observers in the population, the tests were run in the following sequence:

I. Single Colors
   A) Magenta (M)
   B) Cyan (C)
   C) Yellow (Y)

II. Two-Color Overprints
   A) Yellow + Magenta (Y+M)
   B) Yellow + Cyan (Y+C)
   C) Magenta + Cyan (M+C)

III. Three-Color Overprints (Y+M+C)

This sequence was selected in order to standardize the viewing order and to reduce fatigue as much as possible allowing that it might be more difficult to detect changes in the single colors than in the two and three-color overprints. Having judged the single colors first, the observer obtained a "feeling" for the testing process.

The sample patches were randomized before each individual observer took the test with the exception of the first two sample patches in each group, which were selected at high and low densities with respect to the reference standard. This procedure enables the operator to determine the process limit. Inconsistencies were detected by the replication of the patch at which the apparent inconsistency was initially indicated. The area of the inconsistency was determined if the observer rejected a sample which had previously been accepted. If the sample, which was rejected, was nearer to the reference standard than one previously accepted, then the magnitude of the inconsistency could be determined within the limits of the reference patch densities. For the majority of the individusls tested, however, there were no inconsistencies, concluding that the testing sequence was correct with respect to variation in solid ink density from the reference standard in each group.

The acceptance or rejection of every sample was recorded on a tally sheet and filed with the observer's name, the viewing conditions, date, location, and other pertinent test information.

The length of time and positioning of the samples was relatively uniform for each observer, since all samples were handled and presented by the author. This gave control of the length of observation for each sample by removing previously viewed samples from the viewing area so as not to influence the observer's decision of the patch currently in view.

CHAPTER V. FOOTNOTES

[1] Evans, Ralph M. The Perception of Color, New York
John Wiley & Sons, Inc., 1974

VI. STATISTICAL ANALYSIS

In order to define the allowable variation in SID of the single colors as determined by the experienced color observer, it is necessary to represent the allowable variation in the overprint colors as density variations in the single colors which may be related to changes in SID on the press.

Utilizing a reference standard and paired comparisons of samples to the reference standard, the allowable variations in SID may be established for the single colors, two and three-color overprints. If the solid ink densities of the single colors and their overprints increase and decrease in sufficiently small increments from the reference standard, then the observer's tollerances with respect to the reference standard may be established. This experimental procedure may be utilized to obtain statistical data which is representative of the allowable variation in the SID of the single colors. The information may be drawn from a population of experienced color observers in process color printing.

Tables 1, 2, and 3 show the single, two and three-color overprint sample patches and their solid ink densities.

Table 1. SINGLE COLORS

Code	S.I.D.	% Acc.
y_1	.83	50
y_2	.92	28
y_3	1.02	71
y_4	1.05	86
*y_5	1.06	100
y_6	1.08	100
y_7	1.09	71
y_8	1.10	86
y_9	1.12	64
m_1	.82	21
m_2	.88	64
m_3	.90	43
m_4	.92	78
*m_5	1.07	100
m_6	1.08	86
m_7	1.10	79
m_8	1.11	71
m_9	1.12	71
c_1	.88	0
c_2	.96	0
c_3	1.12	14
c_4	1.38	93
*c_5	1.40	100
c_6	1.44	93
c_7	1.48	71
c_8	1.52	79
c_9	1.54	79

*Standard

Table 2. TWO-COLOR OVERPRINTS

Code	S.I.D. Y	+ M	% Acc.
Y_1M_{10}	.86	1.18	7
Y_2M_9	.87	1.18	29
Y_3M_8	.88	1.17	43
Y_4M_7	1.05	1.04	100
*Y_5M_6	1.06	1.07	100
Y_6M_5	1.24	.86	0
Y_7M_4	1.27	.82	0
Y_8M_3	1.26	.80	0
Y_9M_2	1.23	.71	0
$Y_{10}M_1$	1.27	.68	0
	Y	+ C	
Y_1C_{10}	.97	1.91	0
Y_2C_9	1.01	1.60	7
Y_3C_8	1.02	1.51	43
Y_4C_7	1.04	1.54	43
*Y_5C_6	1.06	1.40	100
Y_6C_5	1.11	1.40	100
Y_7C_4	1.14	1.36	93
Y_8C_3	1.24	1.30	0
Y_9C_2	1.30	1.30	0
$Y_{10}C_1$	1.32	1.34	0
	M	+ C	
M_1C_{10}	.83	1.96	0
M_2C_9	.85	1.93	0
M_3C_8	.89	1.93	0
M_4C_7	1.00	1.53	100
M_5C_6	1.03	1.45	100
*M_6C_5	1.07	1.40	100
M_7C_4	1.17	1.45	64
M_8C_3	1.28	1.40	21
M_9C_2	1.37	1.25	0
$M_{10}C_1$	1.35	1.19	0

*Standard

Table 3. THREE-COLOR OVERPRINTS

Code	S.I.D. Y	+	M	+	C	% Acc.
*N	1.06		1.20		1.40	100
Y_1	1.05		1.00		1.04	0
Y_2	1.04		1.04		1.05	0
Y_3	1.07		1.18		1.00	0
Y_4	1.09		1.13		.99	0
$(YM)_1$	1.09		1.14		1.17	57
$(YM)_2$	1.12		1.07		1.18	43
M_1	.90		1.40		1.05	7
M_2	.90		1.41		1.01	0
M_3	.66		1.52		1.19	0
M_4	.72		1.52		.98	0
$(MC)_1$	.90		1.40		1.24	7
$(MC)_2$	.69		1.50		1.33	0
C_1	1.09		1.17		1.42	100
C_2	1.01		1.03		1.23	71
C_3	1.04		1.01		1.35	64
C_4	1.06		1.21		1.40	43
C_5	1.10		1.16		1.43	43
$(YC)_1$	1.07		1.24		1.20	43
$(YC)_2$	1.11		1.02		.97	0

*Standard

These patches were utilized to carry out the experiment. The data in the column labeled percent acceptance (% Acc.) represents the ratio of the number of observers who accepted the sample patch to the total number of observers. One hundred percent (100%) is representative of acceptance by all observers tested. The reference standard is denoted by an (*) and by definition is 100% percent acceptable. In Figures (2A, 2B, and 2C) the Allowable Variation in SID of the single colors is shown for all observers tested. The bar graphs are derived from accepted samples for all observers. The variation in the single color with an overprint color is also shown. The letter "S" denotes the position of the standard with respect to the samples. The bar graphs indicate that there is greater allowable variation in the solid ink density of the single colors alone than in the overprint colors with respect to the reference standard. The greatest allowable variation in solid ink density is shown in the decreasing direction in the magenta (M), and Yellow (Y). The greatest allowable variation in SID for the cyan single color is exhibited in the increasing direction from the reference standard.

In the two-color overprints, magenta-reds are preferred to yellow-reds, indicating that it is desirable to run the magenta solid ink density on the high side while controlling the yellow solid ink density at a relatively low

ALLOWABLE VARIATION IN SOLID INK DENSITY OF THE TRAINED COLOR OBSERVERS TESTED

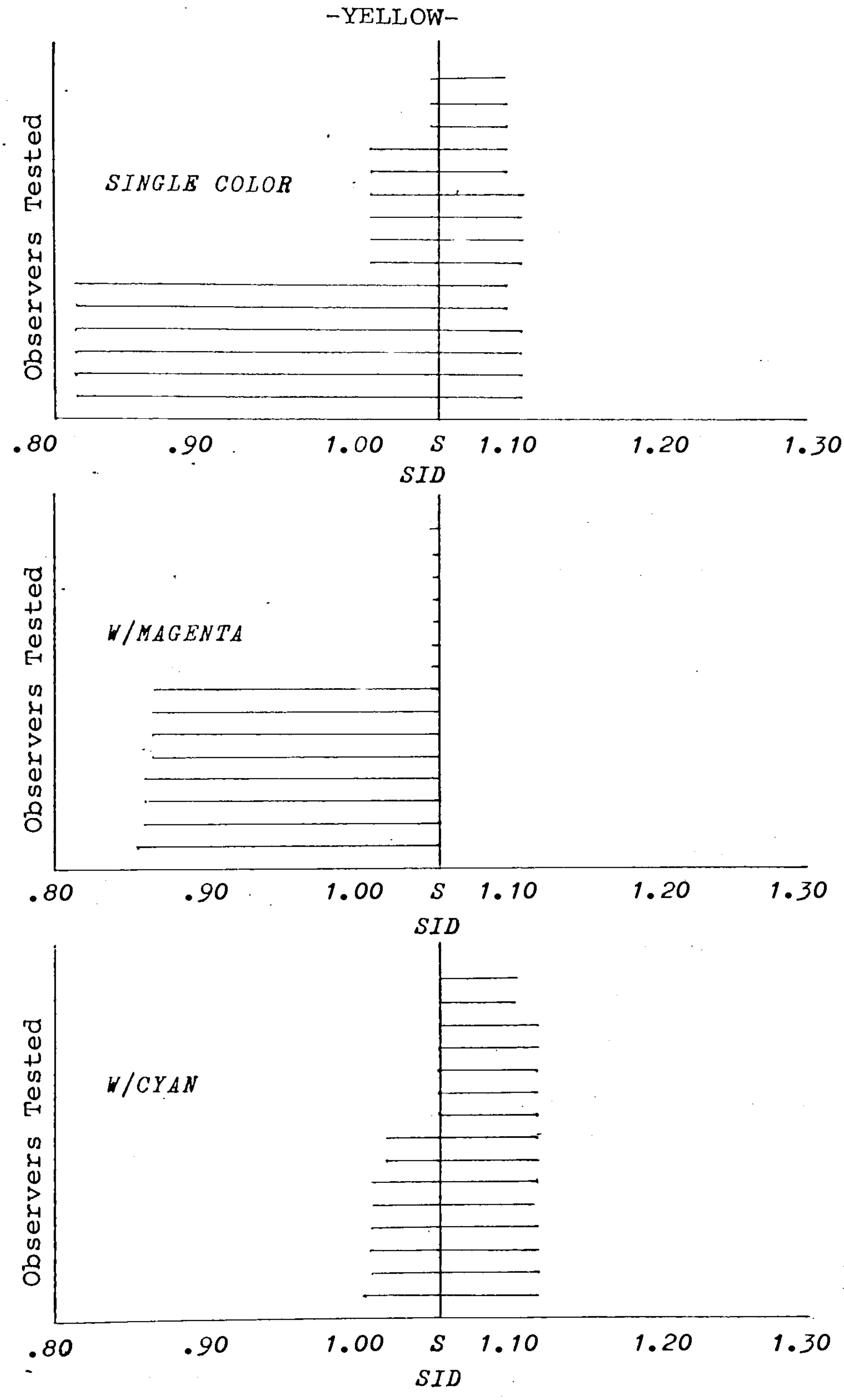

Figure 2A.

ALLOWABLE VARIATION IN SOLID INK DENSITY
OF THE TRAINED COLOR OBSERVERS TESTED

-MAGENTA-

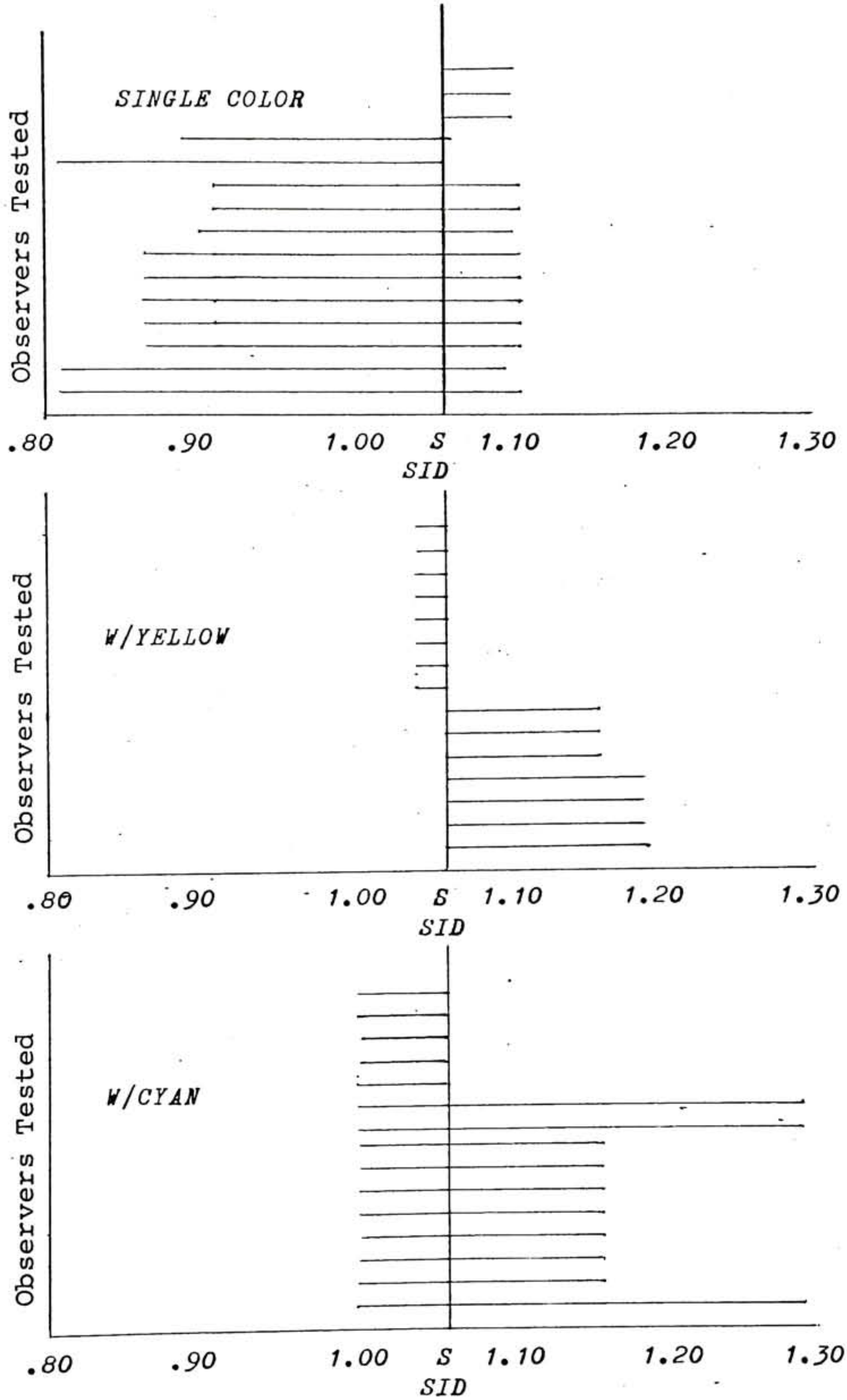

Figure 2B.

ALLOWABLE VARIATION IN SOLID INK DENSITY
OF THE TRAINED COLOR OBSERVERS TESTED

-CYAN-

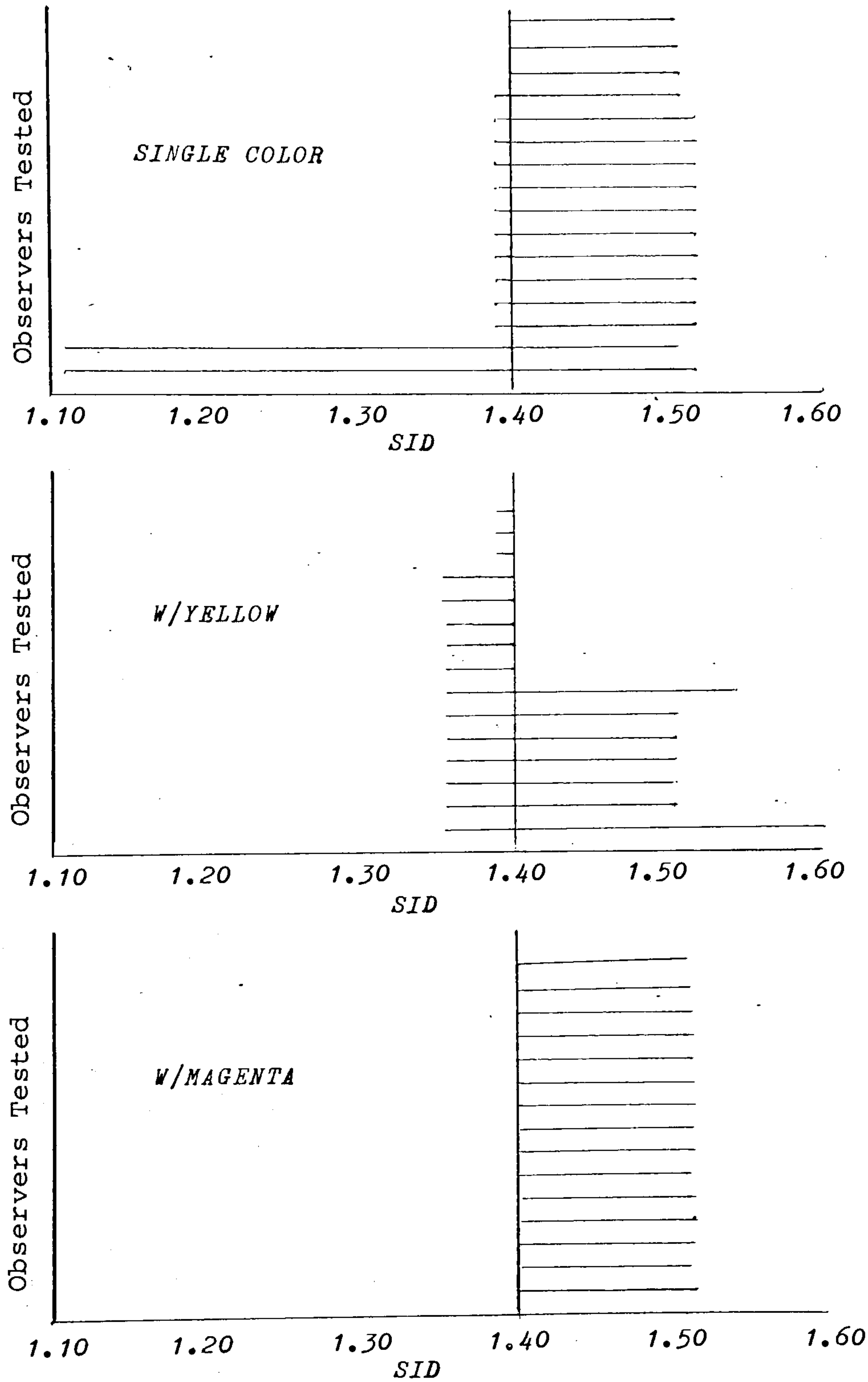

Figure 2C.

level. In the green (Y+C) overprint color there is evidence to indicate that it is important to control both the cyan and yellow solid ink densities. In the blue (M+C) overprints, magenta-blues were preferred to cyan-blues, indicating that it is desirable to run the magenta SID on the high side while controlling the cyan SID within closer tollerances with respect to the reference standard.

In the three-color overprints, greater variation in the magenta and cyan solid ink densities was allowed than in the yellow SID. Because of experimental design, it is difficult to determine the magnitude of the allowable variation in SID in the three-color overprints. Ideally the reference standard should be neutral. The patch which represented the reference standard for the three-color overprints in this experiment was not a true neutral. Furthermore, the density increments of the sample patches were not sufficiently small to enable exact determination of the allowable variation in solid ink density in the near neutral region. From the data obtained, it is evident that the observers tested failed to accept sample patches with relatively small changes in SID in the three-color overprints as compared with the single colors and two-color overprints.

The standard deviation of the allowable variation in solid ink density of the single colors and overprints is shown in Table 4. The results indicate that the greatest allowable variation in solid ink density is exhibited in the single colors. There is a significant decrease in the standard deviation of the single colors in the overprints as compared to the single colors alone. There is also evidence to indicate that it may be more important to monitor the effect of the single colors on the overprints than the single colors alone. Data shown on pages 30, 31 and 32 indicates that the acceptability limits of the single colors on the overprints are significantly smaller than the single colors alone. There is additional evidence indicating that the allowable variation in the solid ink density of the single colors in the three-color overprints is smaller than the allowable variation in SID of the single colors in the two-color overprints.

The ranges of the allowable variation in SID of the single colors, two and three-color overprints is shown in Table 5. The single colors alone show greater allowable variation in SID than the single colors in the two-color overprints. These figures are based on the average ($\bar{X}$) high and low acceptable SID of the sample patches which were viewed by the experienced color observers. The results correlate with the standard deviations of the allowable variation in SID previously mentioned. In the three-color overprints, however, the allowable variation in SID is large in comparison to the two-color overprints with the exception of the yellow single color. This may

Table 4.

STANDARD DEVIATION OF ALLOWABLE VARIATION IN THE SINGLE COLORS AND OVERPRINTS

YELLOW

Single Color	.077
w/Magenta	.069
w/Cyan	.030

MAGENTA

Single Color	.081
w/Yellow	.040
w/Cyan	.060

CYAN

Single Color	.077
w/Yellow	.043
w/Magenta	.058

Table 5.

ALLOWABLE VARIATION IN S.I.D.
(Average Ranges)

SINGLE COLORS

	y	m	c
$\bar{X}$ High	1.11	1.11	1.54
*Std.	1.06	1.07	1.40
$\bar{X}$ Low	.92	.89	1.38
Range	.19	.22	.16
Var. up	.05	.04	.14
Var. dn.	.14	.18	.02

TWO COLOR OVERPRINTS

	Y	+ M	Y	+ C	M	+ C
$\bar{X}$ High	1.06	1.15	1.14	1.54	6.16	1.53
*Std.	1.06	1.07	1.06	1.40	1.07	1.40
$\bar{X}$ Low	.90	1.07	1.04	1.36	1.00	1.44
Range	.16	.08	.10	.18	.16	.09

THREE COLOR OVERPRINTS

	Y	M	C
$\bar{X}$ High	1.12	1.21	1.43
*Std.	1.06	1.20	1.40
$\bar{X}$ Low	1.01	1.01	1.17
Range	.11	.20	.26

be attributed to experimental design in the three-color overprints which has been previously discussed.

VII. CONCLUSIONS

1. Evaluation of the data contained in this study does answer the hypothesis as stated earlier. The densitometric values have been established by these experienced color observers to indicate the allowable variation in solid ink density of the process colors that the observers will accept when judging the overprints of process inks. The ranges that were accepted by the observers tested were:

Yellow	0.13
Magenta	0.12
Cyan	0.13

2. The same group of observers also evaluated samples of single colors alone to determine their levels of acceptability. After close evaluation and statistical analysis of the data, the solid ink densities of the process inks were determined. The ranges of acceptability were:

Yellow	0.19
Magenta	0.22
Cyan	0.16

3. Since these ranges are larger than those ranges accepted for each of the overprints, it may be assumed that these observers were more critical of hue changes in the overprint colors than they were of the inking level of individual process inks printed alone.

4. The standard deviations of allowable variation in solid ink density (SID) of the single colors, as determined by a visual evaluation of the overprints were:

Yellow	0.077
Magenta	0.081
Cyan	0.077

These values represent changes in solid ink density and may be related to density measurements on the press sheet during a run.

5. Another significant finding seems to indicate that all of the ranges for individual process colors are significantly greater than those usually assigned to good quality printing such as ± 0.05. The ranges in some instances exceeded 0.40 and the average ranges for all the single colors in the overprints was 0.20.

6. There was a strong tendency to accept greater variability when the solid ink density increased in the overprint colors than when it decreased.

7. In the two and three-color overprints an increase in the cyan and yellow SID's was allowed more than a decrease in SID. A majority of the observers preferred an increase in the magenta SID as opposed to a decrease in SID for both single colors and overprints. This indicates that it is desirable to run the magenta SID on the high side while

controlling the cyan SID within closer tollerances with respect to the reference standard or approved press sheet.

8. Magenta-reds were preferred to yellow-reds, indicating that it is desirable to run the magenta SID on the high side while controlling the yellow SID at a lower density.

9. The experienced color observer: a) tended to prefer blue-reds over orange-reds, and b) accepted greater variation in lightness than in hue and, therefore, would not accept as much hue change as lightness change.

10. There was no significant difference in the variation in SID accepted in the two versus the three-color overprints indicating that it is important to monitor all overprints.

IMPLICATIONS

Findings from this thesis indicate that it is difficult to assign exact densitometric limits to the process colors during printing. However, this group of observers, which is representative of high quality color printers, allowed far greater variation in density than $\pm.05$ which is currently accepted in industry today. Therefore, it may be unrealistic and unnecessary to control solid ink density within such small tolerances for quality process printing.

As indicated by the thesis of D. Lake (Rochester Inst. of Tech., 1979), many pressmen utilize ink density variation to control consistent color or hue in the overprints at the press. This technique should be promoted rather than discouraged. If changes in solid ink density contribute to visual changes in colors in the press sheet, then accurate and consistent color reproduction may be achieved when comparing the run to a standard.

Information contained in this thesis indicates that it would be useful to monitor the single color component in the overprints. An indepth study of hue change in the two and three-color overprints as it relates to changes in density at the press might provide additional useful information towards a better understanding of variables associated with process color printing.

Today's technology allows for accurate on-line density monitoring during process printing at the press. However, control is only useful when applicable to color changes on the press sheet. It is, therefore, imperative that standards which are applied to process color printing be accurate and consistent for all types of work.

In conclusion, this author hopes that the information set forth in this thesis will provide the printer with greater insight and knowledge of process color printing.

LIST OF REFERENCES

Arens, Hans Colour Measurement, Focal Press, London 1967

Billmeyer, Fred W./Saltaman, Max Principles of Color Technology, John Wiley & Sons, New York 1966

Bruno, Michael H. "What Is Color?", Printing Plates Magazine, November 1974, pp. 3-5

Committee on Colorimetry, Optical Society of America The Science of Color, Thomas Y. Crowell Co., New York, NY 1953

Elzinga, Roel "Reflection Densitometers: Precise Or Inaccurate-It's All Up To You," Inland Printer/American Lithographer, July 1975

Evans; Hanson; Brewer The Principles of Color Photography, Eastman Kodak Company, John Wiely & Sons, Inc., New York 1953

Floyd, Oliver "Measuring And Controlling Colour," Lithoprinter Magazine, May 1975, pp. 27-29 and 31

Gaston, John G. III "Color Perception," Research Paper, Harrow College of Technology and Art, Middlesex, England, 1972

Guy, Paul Process "Color Reproduction," Book Production Industry Magazine, September 1957, pp. 39-44

Hunt, Robert W. The Reproduction of Color, Fountain Press, London, April 1975

Johnson, A.J. An Evaluation of Proposed Standards for the Determination of Colour Differences and the Colour Rendering of Reproduction Systems, International Conference, London, April 1975

Lehman, Eugene B. "The Color On The Paper-Or The Swatch?" Reproduction and Review Methods Magazine, August 1975, pp. 19-20

Mac Adams, David L. "Color Essays," The Journal of the Optical Society of America, (JOSA) May 1975, pp. 483-92

LIST OF REFERENCES - continued

Marcus, Robert T. "Step Size In The Munsell Color-Order System by Pair Comparison Near 5y7.5/1 and Bisection Near 10 r 7/8," Journal of the Optical Society of America, February 1975

Pearson, Milton L. Conversion of a Densitometer to a Colorimeter, Rochester Institute of Technology, Graphic Arts Research Center, 1970

PIRA/RPS/IARIGAI International Conference on New Developments and Application of Photography in Printing "Recent Developments in Densitometry, April 1975

PERI Staff, "Reflection Densitometry in Controlling Proofing," Photoplatemaker's Bulletin, Vol. 63 No. 12, May 1974

Powers, Stanley A./Miller, Oran E. "Pitfalls of Color Densitometry," Photographic Science and Engineering Magazine, Vol. 7 No. 1, January-February 1963 pp. 59-67

Richardson, G. W. "Color Matching," Gravure Technical Association Bulletin, Winter 1974

Siripant, Sakda "Analysis of Color Errors and Their Sources In A Color Reproduction Process," Thesis-Rochester Institute of Technology, School of Printing, 1970

Southworth, Miles "How Densitometers Handle Different Types of Density," Printing Impressions Magazine October, 1974 "Calibration and Use of Densitometers," Printing Impressions Magazine, March 1975/ "How To Get Densitometers To Agree," Printing Impressions Magazine, May 1975

Wurzburg, Francis L. "Color For Printers: What You Should Know About How The Eyes Respond To Color," Printing Impressions Magazine, November 1974, pp. 64-65, 70

Yule, J. A. C. Principles of Color Reproduction, John Wiley & Sons, Inc., New York 1967